6.0 AIRPORT FACILITIES

6.1 CONCEPT DESCRIPTION

The FAA tasked the FTIHWG with developing conceptual methods to

- Introduce nitrogen gas into designated airplane fuel tanks to displace the oxygen in the unfilled portion of the tank (i.e., "ullage washing").
- Saturate the jet fuel held in airport storage facilities (i.e., trucks and fuel-farm storage tanks) with nitrogen (i.e., "fuel scrubbing").

In response, the FTIHWG has developed appropriate design concepts to describe the infrastructure necessary to manufacture, store, and distribute the required NEA and nitrogen-saturated fuel (NSF) from permanent airport facilities.

The following sections summarize the various design scenarios that address the on-airport manufacturing and distribution—both fixed and mobile—of NEA and NSF to the wings of airplanes under consideration for inerting.

Sections 6.1.1 and 6.1.2 describe ullage washing and fuel scrubbing. The initiating FAA task requirement can be found in appendix A, Tasking Statement.

6.1.1 Ullage Washing

Ullage washing removes a large portion of the oxygen gas from the air in the fuel tank ullage. Because fuel vapors cannot ignite unless a sufficient amount of oxygen is present to support and propagate the combustion, reducing the oxygen concentration within a tank eliminates or greatly reduces the ability of an ignition source to cause a constant-volume combustion of the tank's fuel vapors.

To reduce oxygen levels, the ullage is flushed or "washed" with a high-purity (97% to 98%) NEA stream that is produced using a membrane gas generator skid and ducted into the fuel tank. This 97% to 98% NEA was chosen as the most cost-effective inerting agent because it is less expensive than higher purity gas but contains half the oxygen content of a 95% inert product. The volume of gas for inerting has been chosen by the Ground-Based Inerting Designs Task Team to be 1.7 times the volume of the airplane tank to be washed, based on an empty tank. These conditions of inerting-agent purity and volume have been shown to reduce oxygen levels within the ullage space of an empty fuel tank to less than 9%. Therefore, no oxygen meter for gas analysis will be needed to verify ullage washing, which helps to minimize complexity. More importantly, in tanks that are even partially full of fuel, the oxygen content is also expected to be reduced to lower than 9% because of the higher actual volume of NEA flowing through the system.

NEA is generated continuously from air using membrane gas separation technology. Essentially, air is compressed, filtered free of solid particles and liquid aerosols, and fed to bundles of hollow-fiber polymeric membranes where the oxygen, carbon dioxide, and water vapor are removed from the nitrogen stream. These gaseous impurities are vented at low pressure while the high-pressure enriched nitrogen product exits the skid at 97% to 98% purity through a surge tank. Backed up by a storage vessel of liquid nitrogen and a vaporizer, a continuous, seamless transfer of NEA will be ensured through the gas supply lines. One large membrane gas generator skid and backup liquid nitrogen tank would be supplied per airport concourse, mainly to minimize the need for long piping runs between terminals. The NEA would then flow through a header located along the roof of each concourse, at a pressure of about 150 psig. The header would be constructed of 2-in-diameter type-K copper tubing. This header would feed an array of metering stations, located one per gate, to supply nitrogen to the airplanes for ullage washing under controlled flow and pressure conditions. A diagram of the membrane gas generator skid at a concourse is shown in figure 6-1.

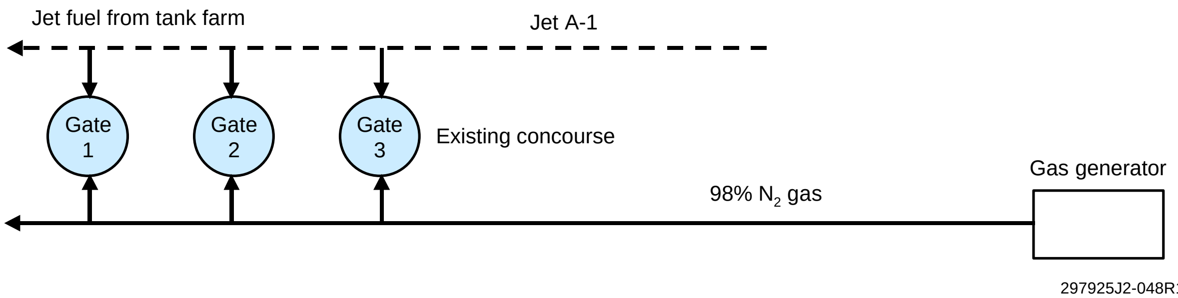

Figure 6-1. Membrane Gas Generator at Concourse for Ullage Washing

At multiple-concourse airports, it would be prudent to consider interconnecting membrane skids between terminals with a larger manifold. While the capital cost of achieving this would be significant, the benefit would be an additional level of redundancy without liquid nitrogen backup if one skid were down for extended maintenance.

The metering stations for injecting NEA gas under flow- and pressure-controlled conditions at each terminal gate are shown in figure 6-2. The station is connected to the concourse NEA header on one end and to a specially designed connector on the airplane at the other end. As stated, this system serves to reduce the oxygen content in the ullage space on airplanes by supplying a given amount of low-pressure NEA to the ullage from a high-pressure source. A solenoid valve and pressure regulator are used to initiate and complete a period of constant-rate gas flow to the airplane. By maintaining this constant flow for a time appropriate to the airplane model, the proper amount of NEA is injected into the ullage. The gas is made available by the regulator at a pressure of just a few pounds per square inch gage. In case of maintenance needs, a shutoff valve would be used to block off the station. The hose reel allows connection to the airplane from a station typically located at the end of the jetway.

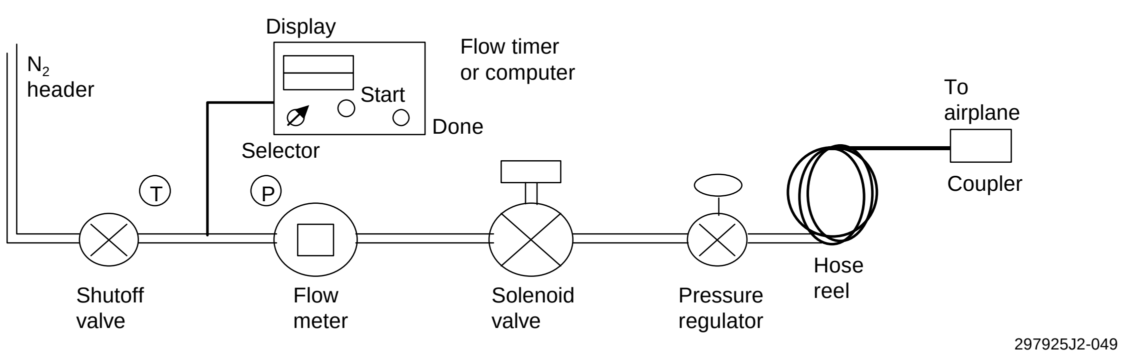

Figure 6-2. Typical Metering Station, Nitrogen Flow, and Pressure Control

The gas metering station would be designed to operate under applicable electrical-safety classifications in an unheated, outdoor service environment where it would be subject to temperature, moisture, and vibration. This station includes a flow meter, flow control terminal, and flow valve. The flow control terminal comprises a lockable, weatherproof housing that contains a flow computer and delivery receipt printer. The flow meter and flow computer deliver a preset quantity of NEA to the airplane's tank ullage. The delivery of this gas to the ullage is measured with reference to standard conditions (i.e., 60°F and 1 atmosphere). Hence, the required preset amount of gas is delivered regardless of the ambient temperature or source-gas pressure.

The flow computer essentially allows gas to flow to the airplane ullage for a given amount of time and then displays the actual volume of gas injected. The flow computer would include a selector to choose the type of airplane being inerted, a start button to control the solenoid valve, an indicator light to show when the job is done, and a dual display to illustrate required and injected gas volumes. In addition, the unit would be configured so that the operator is required to perform a security check (e.g., input an authorization code) to access the system initially. Stored within the flow computer, the appropriate inerting time will produce, at a given constant-rate gas flow, an inert ullage space in the tank above its fuel or within its entire volume if it is empty.

To inert a 737, for example, an operator would connect the coupler to the airplane, select the appropriate position on the selector, and verify the correct pressure on the flow control display. The upper display on the flow computer would show the volume required for ullage washing of a 737 airplane (e.g., 1,360 standard cubic feet [SCF]). The operator would then depress the start button. An NEA flow of 100 standard cubic feet per minute (SCFM) would occur for 13.6 min to produce the recommended volume of NEA for the 737 in this example. Then the indicator light would illuminate (indicating the task is done) and the solenoid valve would shut. The lower display would read 1,360 SCF, reflecting the total of the cumulative gas flow through the metering system at standard conditions. If the value were low, the operator could adjust for more NEA into the ullage to satisfy the requirement. The operator could either verbally inform the flight crew that the airplane has been inerted, or print a written receipt to notify them. This data could also be sent by means of a communications link to a central computer, if preferred.

Maintenance issues related to ullage washing are anticipated to be reasonably light because much of the equipment is passive. In general, the only devices containing moving parts are the solenoids in the flow valves at the metering stations and the air compressors and filters on the membrane gas generator skids. The membrane fibers are passive physical barriers with long lives when adequately protected from chemical attack, liquid impurities, and temperature and pressure excursions. A person skilled in electrical, piping, and instrument issues should be able to handle all routine and breakdown maintenance work on the metering stations at the airport easily.

Ullage washing systems will have to be customized for each airport. Nevertheless, major components required for design of a fixed, ground-based ullage washing system for various classifications (i.e., sizes) of airports may be found in the generic layouts presented in appendix E, Airport Facility Task Team Final Report.

Mobile Ullage Washing

Where it is not practical to supply a land-based source of nitrogen to ullage wash airplane fuel tanks at the loading gate, remote mobile nitrogen-dispensing equipment will be required. This equipment can be either mobile nitrogen-generating equipment, or liquid nitrogen tankers with vaporizers to convert the liquid to a gas.

Two factors have influenced selection of nitrogen-generating equipment over liquid nitrogen and vaporizing equipment for presentation in this report:

- Training and related safety issues associated with handling cryogenic liquids.
- Cost of ongoing purchase of liquid nitrogen compared with costs of generating gaseous nitrogen directly from the air using compressors and high-purity nitrogen membranes.

The design of mobile ullage washing vehicles will emphasize ease of operation by allowing operators to select predetermined automatic cycle times specific to each airplane category. Inerting vehicles will be designed with a high-volume-output, screw-type compressor, appropriate filter, high-purity nitrogen separators, specially designed meter, pressurized nitrogen storage tanks, and a related automated control system. A vehicle brake interlock system is required to ensure that delivery hoses and nozzles are properly stowed before the truck's brakes are released.

The overall size of mobile NEA-generating equipment could become an issue because of the number of high-purity membranes required. When consideration is given to washing the ullage of the CWTs of large transport airplanes and to possibly providing "makeup" nitrogen to hold refueling tankers inert, size quickly becomes an issue.

Current ramp congestion dictates that mobile ullage washing use the smallest package and vehicle footprint possible to accomplish the task.

It is estimated that to service remotely parked or operated airplanes, especially freighters, and as a backup for land-based systems, mobile ullage washing vehicles will typically represent between 65% and 85% of the number of refueling tankers operating at a particular airport. Adding mobile inerting processes at the terminal gate is certain to exacerbate complications associated with congestion around airplanes. There are a number of existing services associated with airport ground operations, including fueling, baggage handling, catering, and cleaning services. These operations require vehicles to travel to and from the airplane in a very short period of time. Therefore, the inerting process could present an increased risk of accidents during operation. Inerting could also decrease the time available to conduct all other ground operations, further adding to the risk.

At small airports, it may be more cost effective to have all mobile equipment, compared to the fixed infrastructure costs.

Problems generally associated with a significant increase in personnel staffing while operating within the same physical area will be present.

Basic concept designs of both mobile liquid nitrogen conversion and NEA-generating ullage washing vehicles are addressed in appendix E.

6.1.2 Fuel Scrubbing

In the ARAC Tasking Statement, the FTIHWG was asked to provide a concept and design methodology for a system that would saturate and maintain aviation turbine (jet) fuel with nitrogen.

The purpose of delivering NSF into the airplane during normal fueling and refueling operations is to minimize the outgassing of entrained oxygen during the takeoff, climb, and cruise flight envelope to supplement the benefit of GBI. Because of the potential impact on fuel properties, the complexity of the processes required, and the costs, the team concluded that fuel scrubbing was not practical.

The 2001 FAA/Boeing flight test showed that the oxygen evolution from the fuel was not significant to the effectiveness of GBI; therefore, scrubbing the fuel would have very little effect on maintaining an inert atmosphere. It also does nothing to alleviate the concern of empty CWTs.

Three concepts were explored during this study:

- Bulk fuel scrubbing by nitrogen injection.
- Bulk fuel cooling using a proprietary process.
- Bulk fuel saturation with carbon dioxide using a proprietary process.

The three concepts are summarized in sections 6.1.2, 6.1.3, and 6.1.4. The detailed discussion and design concepts covering these fuel modification processes are addressed in appendix E.

Fuel Scrubbing by Nitrogen Injection

In order to prevent the oxygen inherently dissolved in the liquid fuel from coming out of solution and polluting the previously washed fuel tank ullage as the airplane climbs, it may be required to scrub the fuel of oxygen before loading onto the airplane. The logical place to do this job is at the fuel storage facility (fuel farm), where the fuel is inventoried and allowed to settle before being pumped into the hydrant system or loaded on mobile refueling vehicles (refuelers). Because jet fuel can preferentially absorb oxygen from the air, the processing technology at the fuel farm needs to focus on removing oxygen dissolved in the liquid fuel, preventing it from reentering the fuel after treatment, and dealing with environmental issues such as VOC emissions. Because of the more aggressive gas and fuel contact that would occur with implentation of fuel scrubbing technology, we anticipate that VOC emissions would be higher than current levels, causing the need for VOC abatement equipment.

The proposed fuel processing system comprises specialized gas generation and application equipment. The high-purity gas-generating skid (99.999% inert) is used to strip the fuel of dissolved oxygen and to blanket the fuel storage tanks at the farm with nitrogen to prevent reentry of oxygen from the air. The fuel scrubbing unit, which is a gas/liquid fuel contacting system, uses pure nitrogen from the high-purity gas-generating skid to replace the oxygen in the fuel. Tank blanketing management systems control the pressure and oxygen concentration in the headspace above the fuel in the individual large storage tanks. Finally, emissions of fuel vapors from the fuel storage tanks and vent gas from the fuel scrubbing unit will be controlled using an environmental abatement system that uses liquid nitrogen to cryogenically condense the VOC vapors from the vent stream and return them to the fuel tanks. Essentially, all technologies work as separate units at the fuel farm to ensure that the fuel delivered to airplanes has been scrubbed of oxygen.

To more easily understand the integration of these various technologies to achieve fuel scrubbing, it is useful to review the existing fuel farm at a typical airport. The simplest configuration is illustrated with three tanks in figure 6-3. Jet fuel from the pipeline continuously fills the tanks as they supply the hydrant system on an active tank-rotation basis. The maximum fuel flow rates for a large airport (e.g., Chicago O'Hare International) from common carrier supply pipelines and withdrawn by hydrant system from storage may exceed 4,000 and 18,000 GPM, respectively. The supply/withdrawal cycle typically involves a piston of liquid fuel filling one tank as a similar flow rate of VOC-laden air exits the vent to maintain a constant in-tank pressure at or near ambient atmosphere. Elsewhere, another tank is being drawn down, aspirating ambient air into the headspace to break any vacuum that is formed by the retreating liquid. The third tank rests for about 24 hr to settle out any free water and debris that may be present in the fuel.

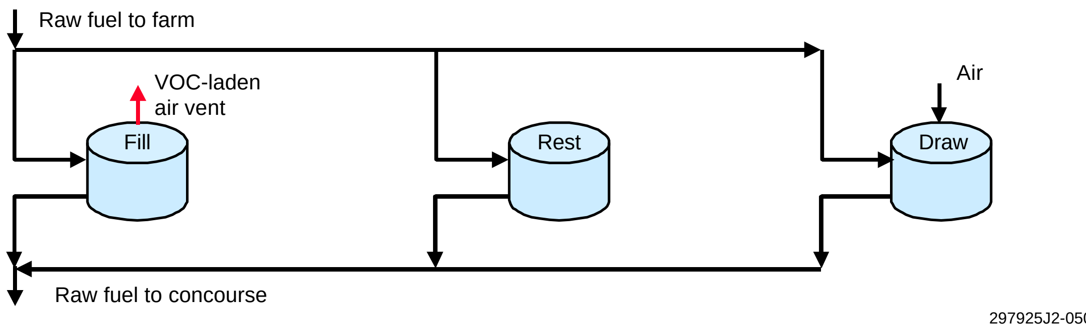

Figure 6-3. Current Tank Farm Configuration

The concept of fuel scrubbing is easily illustrated with some relatively minor additions to the current piping configuration at a fuel farm (fig. 6-4). With this new approach, raw fuel containing 50 to 100 p/m of dissolved oxygen enters the fuel scrubbing unit and is stripped of the oxygen through intimate contact with a stream of high-purity nitrogen gas. The nitrogen replaces the oxygen dissolved in the liquid and dilutes the oxygen gas given off by the fuel. Approximately two volumes of nitrogen gas are required for each volume of fuel processed. The result is a fuel scrubbed of oxygen to about 5 p/m. It has been estimated that the outgas that exits the fuel scrubbing unit contains about 1.5% oxygen and about 0.5% VOC vapors.

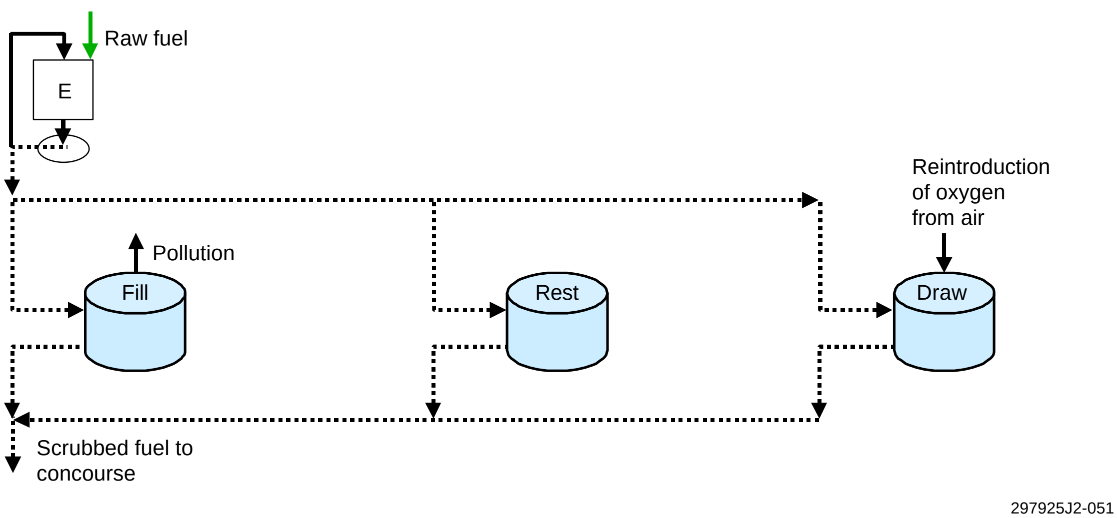

Figure 6-4. Fuel-Farm Piping With Added Fuel Scrubbing Unit

Two issues remain with this level of fuel processing, however. The outgas displaced from the fuel tank being filled and the gas that is vented from the fuel scrubbing unit, both of which contain oxygen and fuel vapors, will pollute the air if not treated. In addition, oxygen in the air aspirated into the fuel tank being drawn down will ruin the fuel treatment previously done by the fuel scrubbing unit. Additional technology needs to be added to that shown in figure 6-4 to avoid these problems and to meet all previously mentioned objectives for fuel scrubbing.

In the complete fuel scrubbing concept shown in figure 6-5, the environmental abatement system and tank blanketing management system have been integrated into the fuel farm to control pollution from VOC emissions and protect against the reoxygenation of the scrubbed fuel in the tanks.

Tank blanketing management systems, mounted one per tank, automate nitrogen blanketing of the tank headspace by measuring and controlling the pressure and oxygen content of the gas above the fuel. In this way, the tanks are continuously maintained at a given pressure and oxygen level.

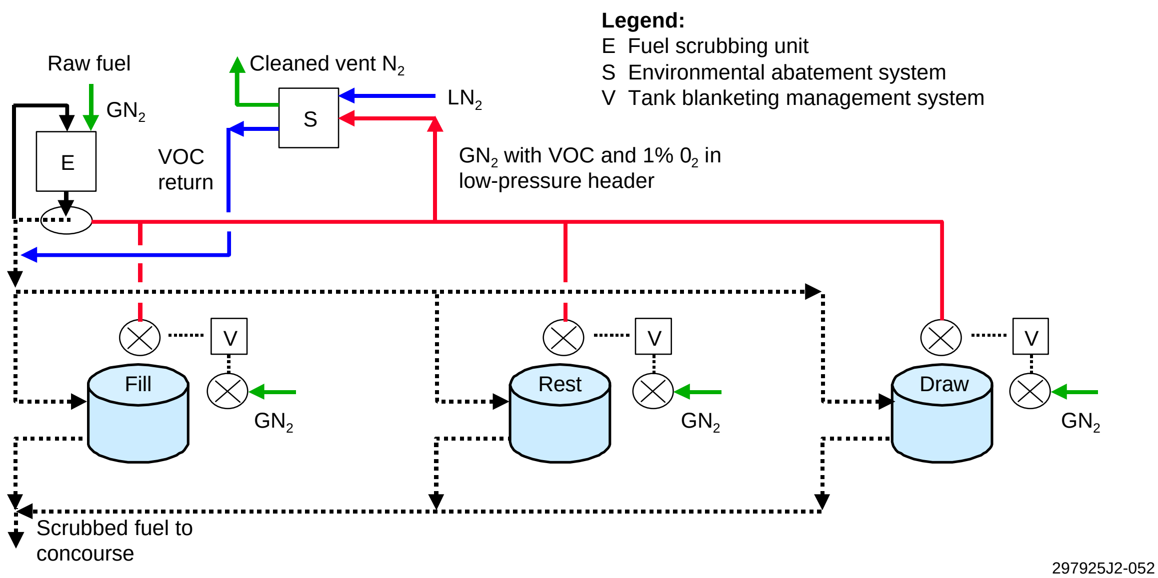

Figure 6-5. Complete Fuel Scrubbing Operation

A low-pressure header connects all vent valves on the fuel tanks and the gas vent from the fuel scrubbing unit to the inlet of the environmental abatement system. The fan on the environmental abatement system will be used to control the backpressure within this low-pressure header.

The process gas flowing through the environmental abatement system contacts stages of increasingly cold heat exchangers to remove nearly 100% of the VOCs by condensation from liquid nitrogen. The liquid fuel is then sent back into the scrubbed fuel line that flows to the storage tank so as not to deplete any compounds out of the normal jet fuel. The nitrogen, which has been stripped of fuel vapors, is then vented to the air or compressed and sent to the concourse for ullage washing if a suitable pipeline is available. The spent nitrogen gas that was vaporized to cool the environmental abatement system is pure and will be sent to the high-purity nitrogen header being fed by the high-purity gas-generator skid.

Distribution of Nitrogen-Scrubbed Jet Fuel by Refueling Tankers

A large number of airports around the world visited by airplanes requiring scrubbed jet fuel might not have the facilities for the bulk distribution of treated jet fuel. These airports may not incorporate a jet fuel hydrant system (underground pipeline distribution network), or the "final rule" from the work of this ARAC study may not apply to a sufficient number of air carriers to warrant bulk fuel scrubbing in the fuel storage facilities. In such cases, limited dedicated treated fuel storage may be preferred for supporting the requirements.

There are many airports that have a jet fuel hydrant system to support the passenger airplane operations, but have cargo and other "feeder" passenger air operations parked in remote (nonhydrant) locations. The mobile refueler tanker method must be modified to enable the supply of the scrubbed fuel to these locations.

This system concept proposes new design criteria and modifications for newly manufactured and in-service refueling vehicles to enable scrubbed fuel to be transported from airport storage to the wing of the airplane.

During airplane refueling, inward venting of the refueler tank is required to prevent collapse of the tank. Airplane refueling would also require NEA to be supplied to the refueler vents to prevent fuel re-oxygenation.

These vents automatically protect the tank from collapse during volumetric contraction during decreases in ambient temperature. Conversely, the vents will also prevent tank rupture resulting from thermal expansion during high ambient temperatures. The current design of typical vapor recovery system equipment does not provide for integration of the existing vent configuration. All vents will need to be interconnected within a system fed by a nitrogen supply. To accomplish this, modification to the refueler will be required.

Relocation of the in-breathing vents may require welding modifications to the tank vessel. If so, these modifications would need to be completed at a facility certified to make such repairs. After modification, the refuelers will mirror the typical vapor recovery system of vehicles transporting flammable liquids on public highways. These vehicles are required by 40 CFR Part 60 to be tested at the time of initial manufacture and periodically thereafter to ensure vapor tightness. It is anticipated that this testing and recertification will be mandated to ensure that only scrubbed fuel is delivered to the airplane and maximum control of VOC emissions is maintained. Relevant portions of 40 CFR Part 60 are found in appendix E.

Modifications include relocation of in-breathing vents to a point where vapor recovery vent hoods and associated piping can connect all vents to a common nitrogen supply. A 1-psig nitrogen pressure stream will be necessary for the vapor recovery system to operate properly at all times.

6.1.3 Fuel Cooling

The Airport Facility Task Team reviewed an airplane fuel tank inerting system design concept developed under a patented process. Because fuel cooling does not directly address the issue of empty CWTs, a supplemental means of inerting these tanks would be required. Time did not allow for a complete review of the technical data. A more detailed description of this process is found in appendix E.

The fuel-cooling concept consists of both refrigerating the fuel and washing the airplane fuel tank ullage with inert gas. The two processes may be used separately or combined. The cooling systems supply fuel to the airplane at less than 40°F. Cooling facilities located away from congestion cool the entire airport fuel supply (hydrant and/or refueler) to less than 40°F. Inerting gas for ullage washing is stored away from congestion and transported to the airplane by gas service vehicles in a cryogenic phase and converted to a gaseous phase for ullage washing. Refinements include combining the two processes into a single system.

6.1.4 Carbon Dioxide Fuel Saturation

The FTIHWG Airport Facility Task Team studied an airplane fuel tank inerting system design concept developed under a patent-pending ERA-7™ process. As with fuel cooling, this system does not directly address the issue of empty CWTs. A supplemental means of inerting these tanks would be required. Because the concept was not sufficiently developed to allow for a complete review of the technical data or a detailed analysis of the system’s infrastructure requirements, the developer’s claims are presented in abbreviated form. A more detailed description of this process is found in appendix E.

The system consists of a carbon dioxide (commercially available gas)/jet fuel mixing apparatus, which preloads the jet fuel with carbon dioxide. In one variation of the airport facility system, the carbon dioxide is derived from a liquefied carbon dioxide storage tank, converted to carbon dioxide gas, and mixed with the Jet A in a gas absorber tower at an optimum gas-to-fuel ratio. Thereafter the carbon dioxide–enriched fuel is stored in a fuel shipping tank with a floating pan, where the combination tank and pan maintain the desired gas-to-fuel ratio of the treated fuel. The carbon dioxide–enriched fuel is then transferred from the shipping tank to airplane refueling sites using the existing fuel pipeline and hydrant systems (for hub airports) or the existing truck delivery system (at nonhub airports).

6.2 AIRPORT FACILITIES

To expand on the data contained in the FAA report, "Cost of Implementing Ground Based Inerting in the Commercial Fleet," the Airport Facility Task Team conducted additional airport surveys at three U.S. and two international airports. This section describes the methods used by the team to develop the design concepts and costs.

6.2.1 Methodology

The Airport Facility Task Team comprises representatives from airlines, oil companies, industrial gas suppliers, airplane manufacturers, civil engineering firms, mobile equipment suppliers, and other airline equipment and service suppliers. The team looked at three different inerting gases, a fuel cooling concept, methods of supply, airport infrastructure modifications, mobile equipment requirements, fuel scrubbing, and the environmental impact of fuel scrubbing. On-site surveys of airport fueling operations were conducted at five airports; design concepts were developed for large, medium, and small airports. Preliminary laboratory testing was performed on the effects of fuel scrubbing on fuel properties and the environment. Cost estimates were determined from the design concepts developed by the team and typical airport construction practices.

The team used the following assumptions during the study:

Ullage Washing

- The process was not to affect airplane turn time.
- Only the CWT would be inerted.
- The process would start when the airplane arrived at the gate (i.e., empty tanks).
- 800 SCF was used as the average gas requirement (i.e., the volume of the small generic airplane model used in the study).
- 1.7 times the ullage volume would be required to perform the task.
- System was sized for a use of 0 to 2.4 times the average to handle peak operations.
- A maximum of 15 min to inert a small airplane would be provided.
- Large and medium airports would use fixed equipment as the primary means for gas supply; and small airports would use mobile equipment.

Fuel Scrubbing

- 50 p/m oxygen content in fuel would be reduced to 5 p/m.
- Fuel scrubbing would be done at the storage facility because of evironmental issues and the ease of siting and constructing fairly complicated processing equipment.

6.2.2 Airport Evaluations

The team conducted on-site airport surveys at Chicago O'Hare, Los Angeles International, Buffalo International Airport, Charles DeGaulle Airport, and London Heathrow to assess the available infrastructure, fueling methods, fuel supply system, and fuel storage system to use in the development of the design concepts and costs of construction. In addition, the data for Atlanta and Atlantic City airports from "Costs of Implementing Ground-Based Inerting in the Commercial Fleet" was used. Figure 6-6 shows a typical survey. One item of note obtained by the survey was the fact that each airport is unique and will require a tailor-made system. There does not appear to be a turnkey solution because of the great differences in airport infrastructures.

AIRPORT FACILITY SURVEY FORM FOR FAA FUEL TANK INERTING

GENERAL INFORMATION

FAA WORKGROUP TEAM MEMBER	Michael Kerr		
AIRPORT	Buffalo Niagara Internatior	LOCATION	Buffalo, NY
CONTACT COMPANY	NFTA	CONTACT NAM	Thomas Kane
PHONE NUMBER	(716) 632-6145 (716) 632-6501 (Fax)	E-MAIL	none

FEED PIPELINE/HYDRANT CHARACTERISTIC No pipeline feed -- Truck deliveries only.

PIPELINE FILL CAPACITY, US GALLONS/DAY	Receives 18 loads of fuel/day -- 100,000 to 120,000 gallons/day					
	700 US GPM Maximum off-loading rate					
HYDRANT WITHDRAWAL CAPACITY	NA					
MAX US GALLONS/DAY	NA					
TYPICAL US GALLONS/DAY	NA					
TIME(S) OF PEAK ACTIVITY						
MAXIMUM HYDRANT PRESSURE RATING, PSI	NA					
TYPICAL HYDRANT PRESSURE, PSIG	NA					
FUEL FILTRATION PRESENT	2 Stage Filter with Teflon 2nd Stage					
FILTER MICRON RATING						
ANY NON-USED PIPELINE FROM TANK FARM	No					
TO TERMINALS? DIAMETER? PRESSURE RATING?						

AIRPORT CONCOURSE

NUMBER OF GATES	25					
GATE NUMBER	1	2	3	4	5	6
HYDRANT OR REFUELER TRUCK FILL(H/T)	All Refueler Truck					
AVERAGE GATE TURNAROUND TIME, HRS						
SURPLUS POWER AVAILABLE	Unknown					
DISTANCE FROM GATE TO PLANE, FT						
ESTIMATE OF AVAILABLE AREA FREE, FT2	Very open areas around Jetways					

REPEAT AS NECESSARY

TANK FARM CHARACTERISTICS All API-650 Tanks

TANK NUMBER	1	2	3	4	5	6
TANK NAME OR DESIGNATION	JetA	JetA	JetA			
TOTAL NUMBER OF IDENTICAL STORAGE TANKS						
PRODUCT STORED	JetA	JetA	JetA			
MAXIMUM DISTANCE TO TERMINALS, MILES	1.5	1.5	1.5			
TANK VOLUME, US GALLONS	225,000	225,000	225,000			
MAX LEVEL, % FULL	23' 10"	23' 10"	23' 10"			
MIN LEVEL, % FULL	1' 6"	1' 6"	1' 6"			
NUMBER FILL CYCLES/MONTH	22	22	22			
NUMBER DAYS FUEL IS SETTLING	1	1	1			
MAX FILL RATE INTO						
TANK, GPM	350					
MAX WITHDRAWAL RATE						
FROM TANK, GPM	600					
MAXIMUM ALLOWABLE WORKING PRESSURE	Line Peak 140 PSI (Working 60 PSI)					
DESIRED TANK MIN						
PRESSURE, IN WC MAX	3/4 Oz					

297925J2-053

Figure 6-6. Airport Facility Survey Form for FAA Fuel Tank Inerting

6.3 IMPACT ON AIRPORTS

The potential impact on current airports identified by the team include

- Labor: Because the inerting process closely parallels the fueling process, it is conceivable that the labor needs would be similar.
- Ramp congestion: The space required for the fixed systems and additional vehicles for the mobile systems could create problems at many large airports where the ramp area is already limited.
- Diversion airports: There could be an impact on smaller airports presently used as diversion airports for larger hubs. The lack of inerting capabilities to handle the occasional influx of a large number of airplanes may limit their usefulness. If GBI does not become a global standard, this could create even greater problems at non-U.S. diversion airports and those used for technical stops.
- Economics: The economic impact could affect commercial airline service at smaller airports.

6.4 ENVIRONMENTAL EVALUATION

General environmental issues are addressed to identify basic direct and indirect environmental impact of ullage washing and fuel scrubbing. The impacts fall into the following categories:

- VOC emissions.
- Airport environment.
- Other environmental issues.

Values and quantities of undesirable materials and impacts are not given in this section. Instead, the impacts are identified as they generally relate to existing airport and airline environmental initiatives. Other than the VOC emissions, which could be mitigated by a costly vapor recovery system, environmental impact from implementing ullage washing and fuel scrubbing is assumed to be relatively minor.

Environmental protection infrastructure must be added to each airport fuel storage facility to mitigate release of VOCs during fuel scrubbing. The systems and equipment include pumps and other electric-motor-driven equipment, above-ground liquid nitrogen storage tanks, gas tanks, and piping.

VOC emission data from a simple experiment from two different sources indicates that substantial amounts of light hydrocarbon molecules would be stripped from the fuel during scrubbing. A vapor recovery system would be an essential component of this system to mitigate the adverse impact on the environment.

All refueler trucks that serve airplanes parked in cargo and other remote areas at an airport with no hydrant system have to be modified. A nitrogen-generating unit added to the rear of the vehicle will maintain an inert atmosphere in the tank headspace and a slight positive pressure in the tank by replenishing with NEA while the truck's fuel tank level is being drawn down during airplane refueling. During the refilling cycle of the refueler, a means of capturing vented emissions would have to be developed. If not properly addressed, these modifications could result in an increase in VOC emissions from this intermediate mobile fuel storage.

During airplane fuel tank ullage washing, it is expected that there would be an incremental increase in VOC emissions. This would result primarily from the application of NEA to airplane tanks that normally would not be disturbed during the routine turn-around activities.

Truck traffic to deliver liquid nitrogen to the tank farm area would result in additional use of fossil fuels if the dependence on liquid nitrogen becomes significant.

The increase in the number of ground service equipment vehicles mandated by these new systems will add to emissions from their internal combustion engines. Alternatively, these emissions could be mitigated if alternative fuel technology were incorporated into new vehicle design.

New construction to support fuel scrubbing at the airport tank farm site will require extensive environmental assessment, existing environmental remediation methods be altered, or remediation be undertaken before the construction of any supporting infrastructure.

Indirect impacts to the environment include negatively affecting airport, city, and regional air quality through the release of excessive amounts of VOCs.

No improvements to the environment were identified for any of the concepts in this report, no data is available on the soil condition of any given site, and no quantified air-emission data is available to establish an emission baseline. A baseline would be useful in measuring incremental impacts to the environment.

6.5 COST-BENEFIT ANALYSIS

Figures 6-7 through 6-10 are economic evaluations of the inerting systems considered by FTIHWG for each type of airport. The estimates used a standard form common to each estimate. The economic evaluation was broken into two parts, capital (nonrecurring) and operation (recurring) costs.

The evaluations include only the cost of construction and maintenance; operator labor costs are not included.

Capital				
Description	Cost per concourse, K	Airport size		
		Large	Medium	Small
Number of concourses		9	2	NA
• System	0	0	0	—
• Site preparation	35	315	70	—
• Piping, hoses, reels, other	408	3,672	816	—
• Electrical power upgrades	500	4,500	1,000	—
• Engineering and soft costs (19%)	179	1,613	358	—
• Contingency (25%)	281	2,525	562	—
Total	1,403	12,624	2,806	NA

Notes:
- Concourse is 20 gates.
- All figures are in thousands of U.S. dollars.

Operational costs per month				
Description	Cost per concourse, K	Airport size		
		Large	Medium	Small
Number of concourses		9	2	NA
• Rent at $20/ft	2	18	4	—
• Lease system if applicable	0	0	0	—
• System maintenance	1	9	2	—
• Maintenance and operation	Per airport	25	13	—
Total		52	19	NA

Note: All figures are in thousands of U.S. dollars.

Figure 6-7. ARAC Facility Estimate—Fixed Ullage System

Capital				
Description	Cost per mobile unit, K	Airport size		
		Large	Medium	Small
Number of mobile units		12	7	2
• System and truck	330	3,960	2,310	660
• Parking and site preparation	1	12	7	2
• Piping, hoses, reels, other	0	0	0	0
• Electrical power upgrades	0	0	0	0
• Engineering and soft costs (19%)	1	12	7	2
• Contingency (25%)	83	996	581	166
Total	415	4,980	2,905	830

Operational costs per month				
Description	Cost per mobile unit, K	Airport size		
		Large	Medium	Small
Number of mobile units		12	7	2
• Rent at $1.0/ft	4	48	28	8
• Lease system if applicable	0	0	0	0
• System maintenance	1	12	7	2
• Power cost	2	24	14	4
• Maintenance and operation	.5	6	3.5	1
Total	7.5	90	52.5	15

Note: All figures are in thousands of U.S. dollars.

Figure 6-8. ARAC Facility Estimate—Mobile Ullage System

Description	Cost per tank, K	Airport size		
		Large	Medium	Small
Per tank at one fuel facility		20	4	2
• System	0	0	0	0
• Site preparation	20	400	80	40
• Piping, hoses, reels, other	101	2,014	403	201
• Electrical power upgrades	30	600	120	60
• Engineering and soft costs (19%)	29	573	115	57
• Contingency (25%)	45	897	179	90
Total	224	4,483	897	448

Operational costs per month				
Description	Cost per gal/ min delivered, K	Airport size		
		Large	Medium	Small
Thousands of gallons per minute		4.5	1.0	0.4
• Rent at $1.0/ft	2	7	2	1
• Lease system if applicable	1	2	1	0
• System maintenance	1	5	1	0
• Inert gas cost	26	117	26	10
• Power cost (if not already included)	0	0	0	0
• Maintenance and operation	2	9	2	1
Total	31	140	31	12

Note: All figures are in thousands of U.S. dollars.

Figure 6-9. ARAC Facility Estimate—Fixed Scrubber System

Capital				
Description	Cost per truck, K	Airport size		
		Large	Medium	Small
Number of existing refuelers		14	9	4
• System and truck	8	112	72	32
• Parking and site preparation	0	0	0	0
• Piping, hoses, reels, other	0	0	0	0
• Electrical power upgrades	0	0	0	0
• Engineering and soft costs (19%)	0	0	0	0
• Contingency (25%)	2	28	18	8
Total	10	140	90	40

Operational costs per month				
Description	Cost per truck, K	Airport size		
		Large	Medium	Small
Number of refuelers		14	9	4
• Rent at $1.0/ft	0	0	0	0
• Lease system if applicable	0	0	0	0
• System maintenance	1	7	5	2
• Inert gas cost	0	0	0	0
• Power cost (if not already included)	1	7	5	2
• Maintenance and operation	1	7	5	2
Total	2	21	14	6

Note: All figures are in thousands of U.S. dollars.

Figure 6-10. ARAC Facility Estimate—Mobile Scrubber System

Capital

Capital costs are those outlays made to design, install, and commission a system concept. Included in the capital estimates are (1) system and vehicle costs, (2) parking and site preparation costs, (3) piping, hoses, and reels for fixed systems, (4) electrical power upgrades, (5) engineering and soft costs, and (6) contingencies.

Operation

Monthly operational costs are those outlays necessary to operate the system concept and are exclusive of capital costs. Depreciation has been omitted. Included in the operations estimates are (1) rent, (2) inerting system lease, (3) system maintenance, (4) inert gas costs for delivered (not generated) gas, and (5) power costs (if not already included in other line items).

Each outlay is defined for reference here.

System and Truck Costs

- Generators
- Storage tanks for liquid nitrogen
- Controls
- Power, lights, and distribution from supply
- System enclosure (if any)
- Rolling equipment (if applicable)

Parking Site Preparation Costs

- Fence
- Rooms, walls, and so on
- Site lighting
- Ramp striping
- Barricades

Piping, Hoses, and Reels for Fixed Systems

- Piping
- Hoses
- Gas distribution hardware to airplane

Electrical Power Upgrades

- New electrical service
- New supply switchboard
- Space costs and new electrical room

Engineering and Soft Costs

- Design—6% of capital cost for the design concept
- Construction administration—3% of capital cost for the design concept
- Program management—6% of capital cost for the design concept
- Construction management—3% of capital cost for the design concept
- Permit and related costs—1% of capital cost for the design concept
- Infrastructure survey—$25,000 per concourse
- Subtotal—19% plus $25,000

Contingencies in Capital Budget

- Unforeseen conditions
- Conceptual unknowns

Rent

- Lease for concourse space at $20 per year
- Lease for site space at $1 per month, per foot

System Lease Cost

- Inert gas generating system lease cost (if applicable)

System Maintenance

- Inert gas generating system maintenance costs by manufacturer (if applicable)

Inert Gas Costs

- Delivery costs
- Capitalized system cost
- Gas cost
- Backup gas costs
- Power and energy for system

Power Costs

- Monthly power costs to run the system (if not built into other line items)

Airport Maintenance and Operation

- Labor to maintain metering, piping, connections, and so on
- Labor to operate (at $25 per hour)
- Spare parts
- Accounting
- Testing and airport certification

6.6 TECHNICAL LIMITATIONS

Given sufficient implementation time and resources, no major obstacles are foreseen, although it will be necessary to prototype a full-scale system to validate the methods and technology. New worldwide airplane interface and safety standards also would be necessary.

The major cost drivers for ground-based systems are developing the infrastructure and the operating labor for the inerting process. Therefore, these limitations do not offer areas of significant cost reduction.

6.7 POTENTIAL IMPACT ON FUEL PERFORMANCE

The Tasking Statement requested that ARAC provide, among other tasks, an evaluation of the feasibility to saturate jet fuel with nitrogen in ground storage facilities, for example, in trucks or central storage tanks. The design concepts for saturating the fuel with nitrogen, also referred to as fuel scrubbing, provoked concerns over maintaining jet fuel integrity during the processing.

A concept and design methodology for a system that proposes to accomplish this task has been developed. During the conceptual deliberations as to how an effective system might be designed, manufactured, installed, and made operational, concern arose with respect to the effects that ullage washing and fuel scrubbing may have on the performance characteristics of aviation turbine fuel. In addition, there were concerns expressed about the environmental impact of the inerting process, especially as a consequence of fuel scrubbing, which involves vigorously mixing nitrogen gas with a high-flow fuel stream.

This section will summarize the concerns, the findings of preliminary laboratory analyses performed by two oil company task team members, and the recommendations for further study into airplane fuel tank ullage washing and fuel scrubbing.

Concerns were raised that ullage washing and fuel scrubbing would degrade certain performance properties of jet fuel by driving off the lightweight molecular ends of the fuel. The light ends influence several specification properties of jet fuel, including distillation, flash point, and freezing point. Another concern expressed was the uncertainty of how these processes might affect the relight-at-altitude characteristics of the fuel. Questions were also raised regarding the performance of additive packages (e.g., antioxidants and antistatic additives) to enhance or modify particular characteristics of the fuel.

To obtain a broader perspective on these questions and other issues, a notice was circulated by means of the ASTM committee charged with aviation turbine fuel specification maintenance (ASTM D-1655) asking all U.S. and non-U.S. refineries and engine, airframe, and component manufacturers to provide feedback and information they may have on the performance characteristics of fuel subjected to ullage washing, scrubbing, or both. Because these inerting concepts were new to many of the responders, more questions were raised than answers received. Additional concerns expressed ranged from the belief that complete engine recertification may be required to the belief that nitrogen inerting would improve at least the fuel stability characteristics and therefore would be a benefit.

The last area of concern that arose during discussions of the fuel inerting concept involved environmental considerations. Flowing nitrogen gas over a partially filled fuel tank and the vigorous mixing of nitrogen gas with fuel during the scrubbing process would, according to general opinion, result in significant VOC release to the atmosphere at airport fuel storage depots. These VOCs would aggravate the already thorny issue of air pollution at and around today's airports. Feedback and factual data were requested from stakeholders, including the EPA. Again, more questions than answers came from this inquiry.

AirBP and Texaco performed elementary experiments on ullage washing and fuel scrubbing using nitrogen and carbon dioxide gases; final reports are in appendix E.

Preliminary results of these experiments indicate that ullage washing and fuel scrubbing with nitrogen gas have little effect on the conventional properties of jet fuel. However, a measurable change in vapor pressure occurred from fuel scrubbing, and the carbon dioxide–scrubbed fuel exhibited an increase in acidity. Significant VOCs were released during both processes, regardless of the inert gas used. VOC release may lead to serious health and safety issues that must be addressed.

Physical Property Changes. One experiment showed that there is an increase in fuel vapor pressure after the scrubbing process. This vapor pressure increase is not totally understood at this time; however, it does suggest that there may be a deleterious effect in controlling the flammability of the airplane fuel tank headspace atmosphere. The increase in vapor pressure may affect the performance of the different fuel pumping devices used on today's airplanes.

There was also a decrease in the fuel's electrical conductivity, which will require further investigation. Changes in this fuel property will require a full understanding of the phenomenon because of fuel handling safety and additive performance issues.

A significant release of VOCs (addressed further in this summary) occurred during ullage washing and fuel scrubbing, which obviously change bulk fuel composition. Removing and recombining the VOC condensate after a vapor recovery process will require additional study to ensure that there is no deleterious effect on engine performance from a reconstituted fuel blend. Although no statistical difference was measured in the fuel's distillation characteristics, flash point, or freezing point, a more thorough analysis of these properties should be performed to verify the preliminary findings. Additionally, because the loss of these light ends may affect altitude relight, a thorough analysis of this characteristic should also be carried out. Unfortunately, this analysis could not be done in the time allotted to this project.

The experiments using carbon dioxide as the scrubbing gas (carbon dioxide–oxygen injection was one of the inerting processes considered during the team's discussions, but time did not allow for a complete conceptualization of this technique) showed a much greater effect on vapor pressure than nitrogen and also increased the acidity of the bulk fuel. This finding was not totally unexpected; prior experience has shown that with water-laden (including dissolved water) mixtures and subsequent carbon dioxide saturation, carbonic acid may form as a byproduct of this chemistry. The formation of any compound that may enhance or accelerate corrosion of the airplane fuel tanks is not a desirable attribute of a fuel.

Industrial Health and Safety Issues. The experiments indicated that the carcinogen benzene may be concentrated in the vapor phase at concentrations that could exceed the 0.1% weight limit by weight established for regulating a material as toxic. This matter is of the greatest concern with regard to employee health and the environment surrounding airport bulk storage depots and will have to be addressed.

An additional employee and facility safety problem is also introduced when fuel is exposed to the scrubbing process, which creates an extremely flammable vapor atmosphere from light-end VOC emissions. Very careful attention will have to be paid in the design of any mechanical equipment used to recover and dispose of VOCs.

Ullage washing will result in the release of a low-oxygen, high-inert-gas concentration mixture (nitrogen or carbon dioxide) from the CWT vents. People working in and around this area may be exposed to air with an oxygen level below that which is required to sustain normal respiration. The hazard level will increase as the number of airplanes in a localized area undergoing the inerting process increases. This asphyxiation hazard must be studied in more depth before any large-scale inerting is implemented.

Environmental Impact Issues With Fuel Scrubbing. The fuel scrubbing process has been shown to release a significant amount of VOCs. These VOC releases were measured in the more than 1% range by volume during the experiments. To put this volume in perspective, it represents an equivalent volume to more than 21,000 gal of jet fuel from a typical 50,000-barrel storage tank found at many airports. This release is expected to occur each time this amount of fuel is received into storage and subsequently processed through the scrubbing cycle. The environmental as well as economic impact of releases of this magnitude will require careful design and operation of costly vapor recovery systems near bulk storage facilities. As more regulatory pressure is exerted on today's management and operators to clean up the air on and around airports, the release of additional pollutants caused by any new process becomes unacceptable, regardless of the perceived benefits.

The EPA representative queried during the feedback process succinctly put future work on this issue into perspective by recommending *(1) a literature search for theoretical and experimental analysis of the effects of fuel tank inerting or similar fuel treatments on engine exhaust emissions, (2) explicit discussion, involving appropriate experts of this concern in FAA rulemaking activities relating to fuel tank inerting; and (3) experimental research to validate expectations regarding impacts of inerting methods on engine exhaust emissions.*

As this discussion indicates, a number of issues need to be addressed and better understood, and solutions need to be found before ullage washing, fuel scrubbing, or both are implemented on a large scale. The following is only a short list of the issues that come to mind.

- The performance characteristics of scrubbed fuel in today's turbine engines need further investigation.
- The impact of ullage washing and fuel scrubbing on employee health and safety will have to be better understood so appropriate action can be taken.
- The impact of ullage washing and fuel scrubbing on the environment will have to undergo an extensive review. There was not enough time or readily available information during this ARAC project to become fully knowledgeable on the subject or propose concept designs to address the impediments identified.

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